HORIZON

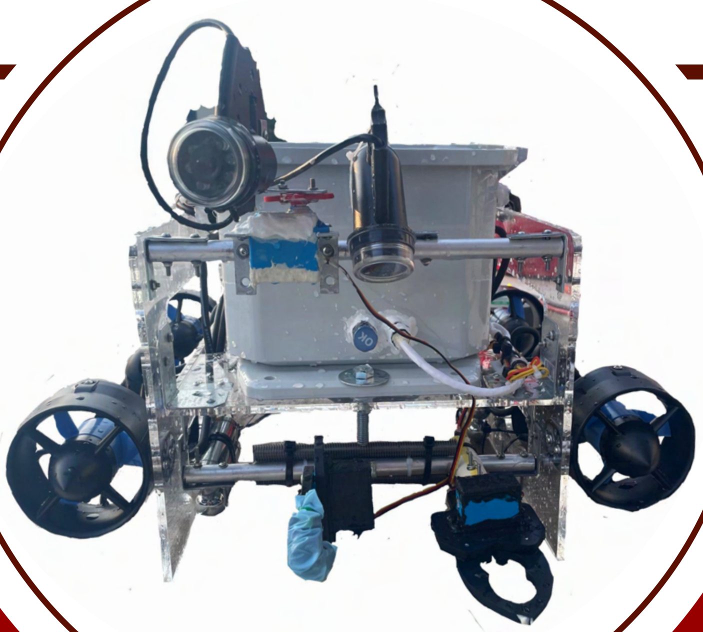
Lenape High School | Technical Documentation

Reverie ROV

LHS Horizon

Lenape High School
Medford, NJ, United States

@LHS_Horizon



EMPLOYEES

Adithya Selvakumar CEO, Control Systems	23'		**Alex Tornese** co-JSO, Control Systems	25'
Vishvajith Jagadeesan COO, Control Systems	25'		**John Shenouda** co-JSO, Mechanical	25'
Akshya Amarnath CDO, Control Systems	25'		**Adam Freedman** co-CMO, Mechanical	25'
Shreeya Soma CFO, Mechanical	25'		**Matthew Pugh** co-CMO, Control Systems, Pilot	25'

MENTORS

Ms. Amy Krevetski

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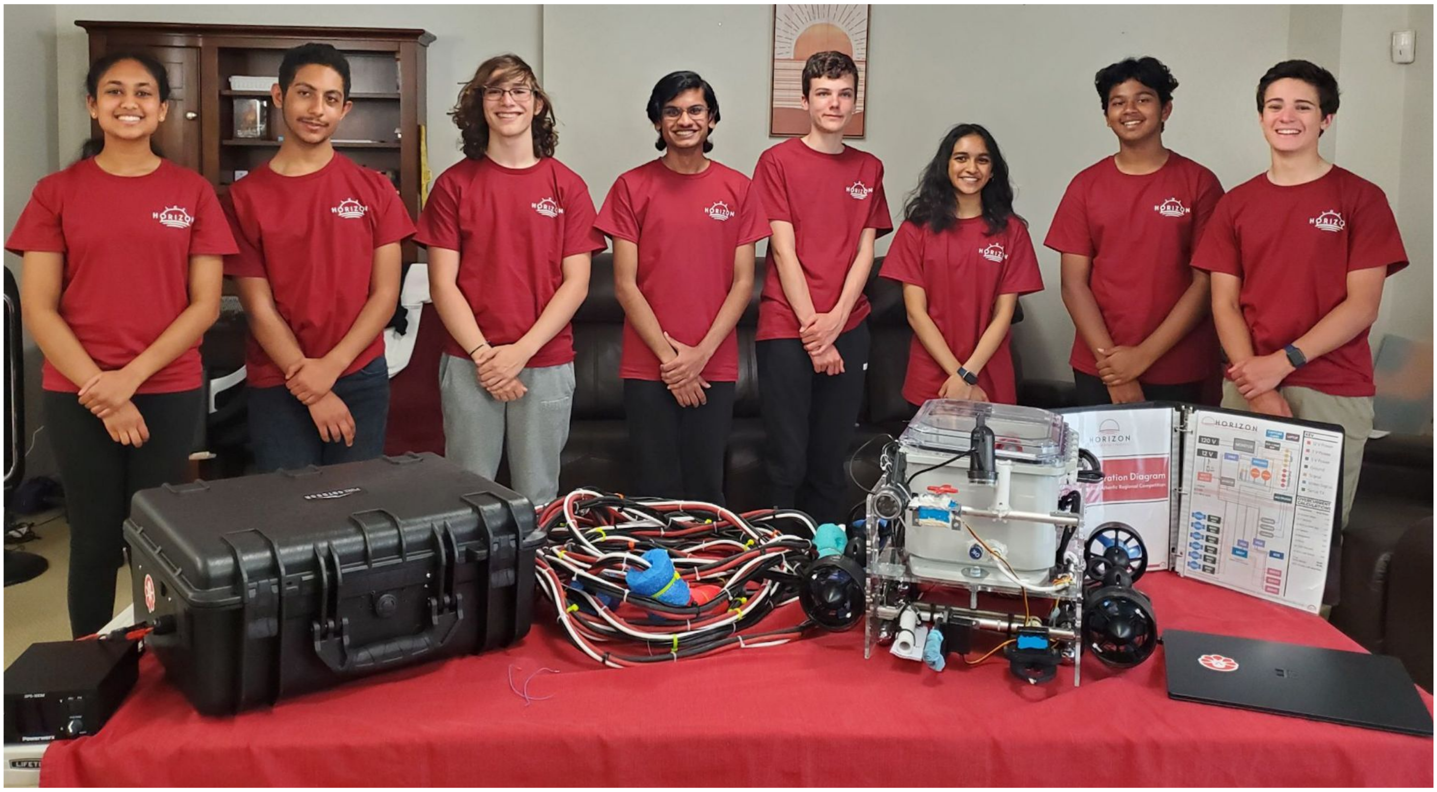
1: ABSTRACT

LHS Horizon is a marine robotics company based out of Medford, NJ. Despite being in its first year of operations, its eight-member personnel has years of experience developing subsea systems.

Reverie is LHS Horizon's latest enterprise, a state-of-the-art Remotely Operated Vehicle (ROV) designed to operate in marine environments around the world. *Reverie* is fully equipped to address the three tasks outlined in the MATE Center's request for proposals (RFP): Marine Renewable Energy, Offshore Aquaculture and Blue Carbon, & Antarctica Then and Now. The release of the RFP coincides with the United Nations' proclamation of a *Decade of Ocean Science for Sustainable Development*, thus tying the company's work to a greater global effort to create improved conditions for the sustainable development of our world ocean.

Reverie is the result of months of prototyping, troubleshooting, and testing and meets the highest quality and safety standards. With features such as a modular frame, cutting-edge electronics, and an expansive software platform including an artificial intelligence model to identify "morts" (i.e. dead fish), *Reverie* is tailored to complete the tasks issued in the RFP. Its dual -manipulator array enables the company to complete several of the aforementioned tasks (repair an inter-array power cable, deploy a hydrophone, etc) and its dynamic vision system ensures the client can map the location of the *Endurance* and determine the biomass of fish samples. This technical document details the research and development processes that resulted in *Reverie*, and the vehicle's ability to satisfy the ever-changing needs of the global community.



Company Personnel
Employees (left to right): S. Soma, J. Shenouda, A. Tornese, A. Selvakumar, M. Pugh, A. Amarnath, V. Jagadeesan, A. Freedman
Photo Credit: A. Selvakumar

2: PROJECT MANAGEMENT

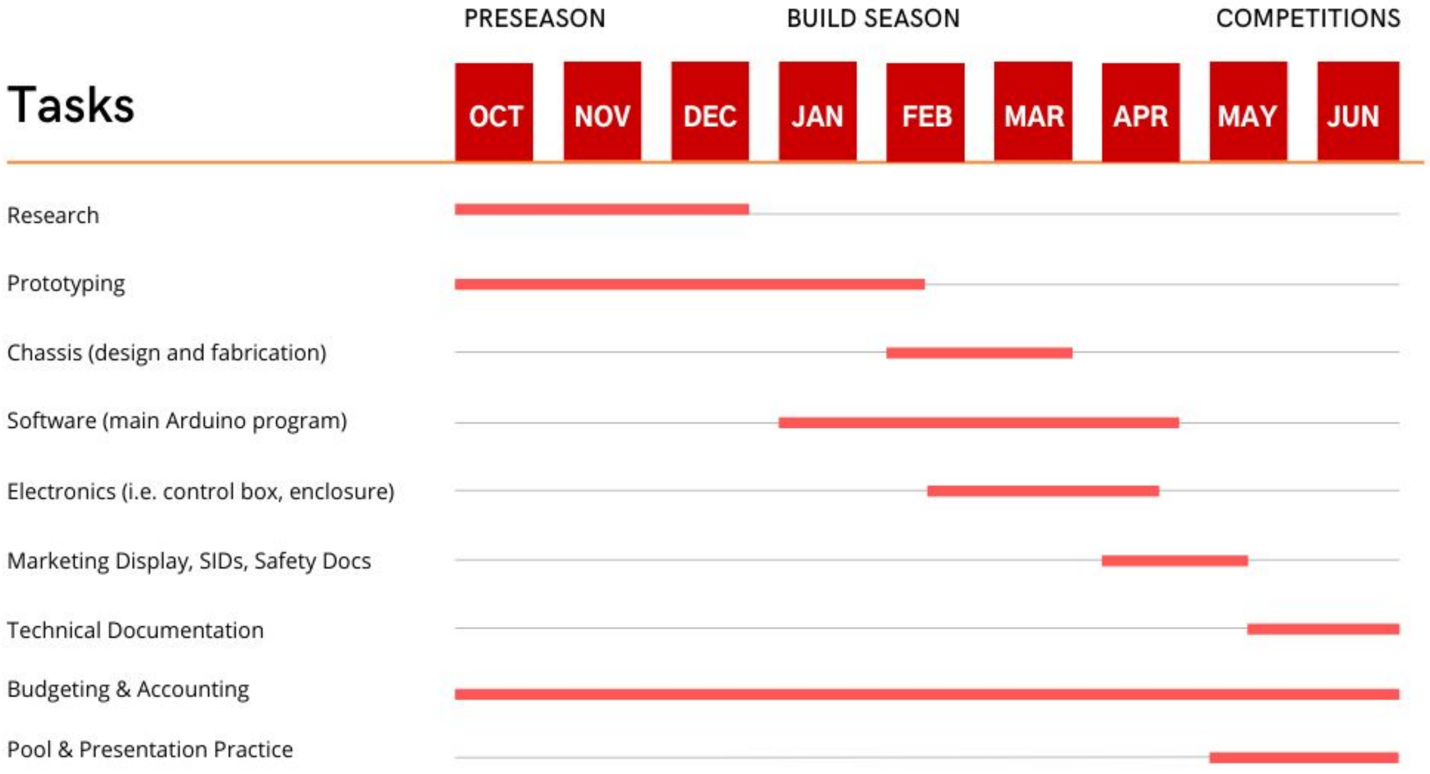
Company Profile

At LHS Horizon, the focus is to deliver innovative, high-quality products tailored to meet and exceed the clients' needs. The company is a first-year robotics startup based in Medford, New Jersey, and is affiliated with Lenape High School. It employs eight high-school students, each of whom specializes in mechanical engineering and/or control systems. Alongside technical responsibilities, each personnel member was designated with a company role. These positions oversee different aspects of the company:

- ★ Chief **Executive** Officer (**CEO**; administration) – Adithya Selvakumar
- ★ Chief **Operations** Officer (**COO**; management & planning) – Vishvajith Jagadeesan
- ★ Chief **Documentation** Officer (**CDO**; documentation) – Akshya Amarnath
- ★ Chief **Financial** Officer (**CFO**; budgeting & finance) – Shreeya Soma
- ★ Job **Safety** Officers (**JSO**; safety) – Alex Tornese & John Shenouda
- ★ Chief **Marketing** Officers (**CMO**; marketing & promotion) – Adam Freedman & Matthew Pugh

Scheduling & Planning

The company's CEO and COO created a high-level project timeline (see Gantt chart below) to enable effective time management. The CEO organized focus groups and facilitated regular debriefs to hold company personnel accountable and ensure crucial tasks were on track for completion. With the COO's help, the CEO referenced the Gantt chart to outline daily and weekly agendas.



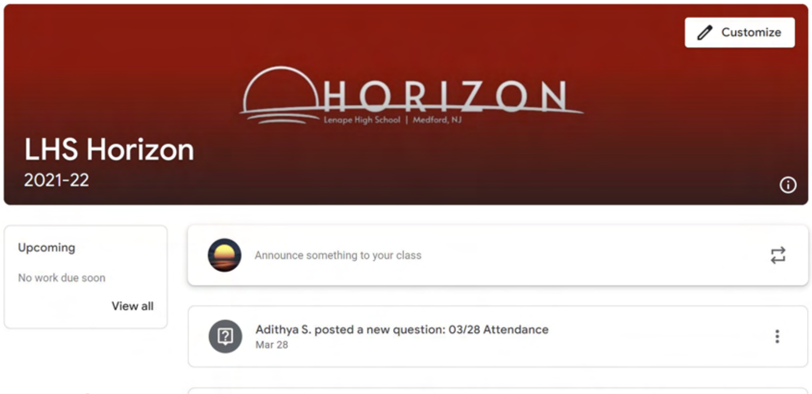
Gantt Chart
Design Credit: V. Jagadeesan

2: PROJECT MANAGEMENT

Mission Objectives and Daily Operational Procedures

Given the nature of long-term projects, and the company being in its first year of operation, resources and protocols were leveraged to meet the objectives outlined in the project timeline and solve day-to-day operational problems.

The company's CEO used online platforms such as Google Classroom and Discord to effectively communicate with company personnel. He used Discord to broadcast announcements; streamlining communication through the Discord platform ensured the whole team was always up to date with the flexible meeting schedule and ever-evolving project requirements. Google Classroom facilitated easy file sharing, and made it simple for company leaders to keep track of attendance and receive one-on-one feedback from personnel.



Adithya S. posted a new question: 03/28 Attendance
Mar 28

Adithya S. posted a new question: Monday, March 21 ~ Meeting Debrief
Mar 21

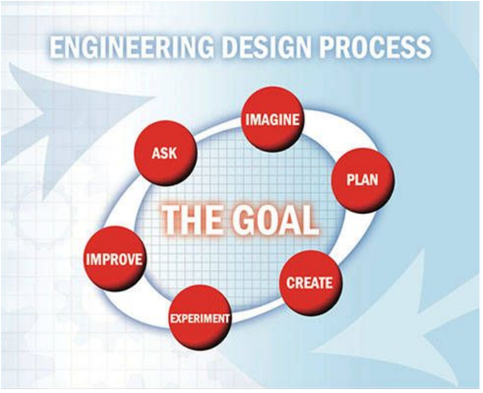
Company Google Classroom
Photo Credit: A. Selvakumar

The CEO and COO made it standard protocol to conduct weekly debrief sessions. They developed daily and weekly agendas and considered the tenets of SMART (specific, measurable, achievable, realistic, and timely) goal setting while allocating resources to the week's tasks. Operational problems are inevitable; setbacks, both technical and interpersonal, come with administrative work. Examples of these include delayed shipments, sudden cancellations from swim clubs, and miscommunication between company personnel. But by making the aforementioned protocol regular practice, the company's leaders were able to identify these issues in a timely manner and adapt plans accordingly.

3: DESIGN RATIONALE

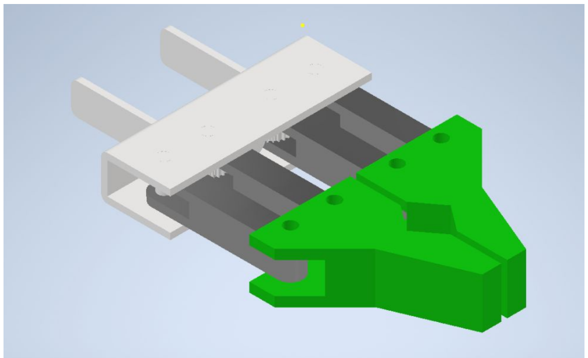
Engineering Design Rationale

Company personnel used the NASA's BEST Engineering Design Model as a **step-by-step planning and design process** to guide research and development (R&D) efforts. Each step contributes to mission success and may be described as follows: *ask* - identify the problem and project requirements & constraints, *imagine* - research and brainstorm, *plan* - sketch possible designs from brainstormed list, ultimately choose a single design to prototype, *create* - construct a prototype, *test* - evaluate the solution through testing, and *improve* - refine design using testing data.



Engineering Design Process
Photo Credit: nasa.gov

3: DESIGN RATIONALE



Linear Actuator Gripper Design
Design Credit: A. Freedman

To demonstrate employees' use of the design process, the document highlights the following design decision. During preseason, the mechanical R&D team was tasked with conducting research into the potential efficacy of a linear actuator powered gripper; the team later outlined a cost-benefit analysis regarding whether company leadership should consider replacing *Reverie*'s servo-powered grippers with this new option. After detailing the project requirements and constraints, employees researched and brainstormed myriad potential gripper models, before landing on the linear actuator and servo models as preeminent options. Company CAD specialists designed both in Autodesk Inventor, and used a **design matrix** to ultimately choose a design to prototype. Ratings are on a scale of 1 to 4, with 4 being the highest possible score. R&D data was considered to make a **thoughtful and balanced trade-off.** The design team chose to forgo the linear actuator model's better grip strength for the servo model's lower cost and increased longevity, in light of the project requirements.

	Cost	Longevity	Ease of Fabrication	Total Score
Linear Actuator Model	1 Linear actuator costs $170. Given cost of screws & gears, entire assembly could cost $200.	2 Model could be prone to breaking due to its large range of motion.	3 Both models are equally easy to build.	6
Servo Motor Model	3 Servo motor costs a more manageable $50.	3 The assembly is smaller and has less moving parts; less likely to break and wear.	3	9

Gripper Model Design Matrix
Design Credit: A. Freedman

Innovation

During the early stages of build season, the company's CEO and COO outlined four focused criteria to guide ROV development; the first of these was innovation, which they defined as "prioritizing modifications that resulted in **higher functionality at reduced costs**". By cementing the concept in the its design methodology, the company ensured innovation was present in its **vehicle design, tools, and even its branding**.

3: DESIGN RATIONALE

One of many examples of the company's design innovation is *Reverie*'s **watertight enclosure subsystem**. Nearly 80% of companies using watertight enclosures in the 2020-21 high-school Ranger class chose the commercial BlueRobotics model. Given the commercial model's high cost and cylindrical shape (which made mounting electrical components in a compact manner impractical), coupled with the inability to lock its o-ring flanges to the acrylic housing, the control systems specialists at LHS Horizon sought an alternative.

Junction Box
Credit: polycase.com

Reverie's watertight enclosure is built from a repurposed junction box. Tether wires enter the box through commercial cable penetrators and a rubber gasket, marine epoxy, and resin serve as waterproofing. Since finalizing the design, the operations team at LHS Horizon is proud to announce it have had zero leaks.

Reverie's custom enclosure is 400% less expensive than the commercial alternative. Its screw-top close is as effective, if not more, than the commercial model's friction-fit flanges. Its rectangular shape makes it simpler to mount to the ROV chassis and compactly house components. This design decision is indicative of the company's four-point design policy which prioritizes innovation.

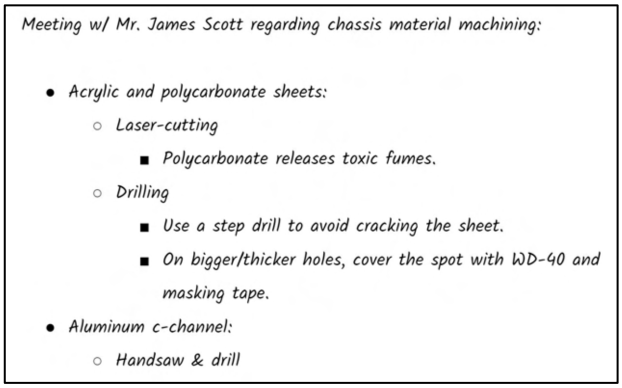
Problem Solving

The second step of the company's guiding process calls upon employees to *imagine*, i.e. conduct thorough research to brainstorm a rational list of design alternatives. To illustrate this process, design leads chose to highlight the decision personnel made to construct *Reverie*'s chassis from acrylic.

	Ultimate Tensile Strength
Acrylic	12,000 psi
Aluminum	45,000 psi
Polycarbonate	10,200 psi

Ultimate Tensile Strength Data
Source: matweb.com

At LHS Horizon, engineers come to the brainstorming table after **rational process** (gathering in-depth research data relating to project requirements). In researching materials for a chassis, employees balanced the project requirements of durability and modularity with company constraints (i.e. the resources & machining methods available to us). The research is both primary and secondary in nature; for example, the mechanical design team not only practiced machining techniques (drilling, using a jigsaw) on potential material choices, but also consulted industry professionals and the MATE Center's technical documentation archive.



Meeting w/ Mr. James Scott regarding chassis material machining:

- Acrylic and polycarbonate sheets:
  - Laser-cutting
    - Polycarbonate releases toxic fumes.
  - Drilling
    - Use a step drill to avoid cracking the sheet.
    - On bigger/thicker holes, cover the spot with WD-40 and masking tape.
- Aluminum c-channel:
  - Handsaw & drill

Notes on Chassis Machining
Credit: S. Soma

In the aforementioned example, engineers noted the chassis material had to be durable and easy to machine. Precise machining (i.e. achieving a high degree of repeatability and accuracy) was a must.

3: DESIGN RATIONALE

In the brainstorming phase, the design team chose to evaluate aluminum c-channel and acrylic and polycarbonate sheets. Secondary data collection proved all materials sufficiently durable. Consultation with industry professionals indicated that both acrylic and polycarbonate sheets were easy to machine using laser-cutting, but polycarbonate would produce toxic fumes. Furthermore, a C-channel chassis would have more parts than a chassis built from an acrylic sheets, contributing to a higher degree of variability. For these reasons, the design team decided on an acrylic chassis; the example indicates the company's brainstorming and problem-solving methodologies.

Systems Approach

Immediately following the release of the MATE Center's request for proposals in December, all LHS Horizon employees met to outline the functional requirements for build seasons, and which components and systems would be necessary to fulfill the aforementioned requirements. The team identified the following basic requirements:

1. A propulsion system capable of providing the ROV with at least three degrees of freedom (moving forward & backward, turning left & right, moving up & down)
2. A vision system that offers the pilot a view of the ROV manipulators, the seafloor (for the flyover of the *Endurance* wreck), and its surroundings
3. A chassis to house motors, cameras, and all other onboard ROV components
4. A manipulator system capable of retrieving mission items (including an inter-array power cable, buoyancy module, hydrophone, ghost net, marine growth, fish stock, etc)
5. A topside control unit (TCU) to house all topside electronics
6. A watertight enclosure (WTE) to house all onboard electronics
7. A tether to connect the TCU to onboard electronics
8. A non-ROV device capable of completing two vertical profiles.
9. A control algorithm that takes pilot input, parses it, and seamlessly outputs to all onboard ROV components
10. Separate artificial intelligence software capable of differentiating morts from live fish

After outlining these requirements, the company CEO divided labor into nine ROV subsystems in the spirit of a **balanced systems approach**.

Mechanical Subsystems	Responsibilities
Propulsion	Choosing motors; deciding on thruster orientation/configuration
Vision	Choosing cameras; deciding on camera orientation/configuration
Chassis	Designing a chassis to house all onboard components
Manipulator	Building ROV manipulators capable of completing all mission tasks

3: DESIGN RATIONALE

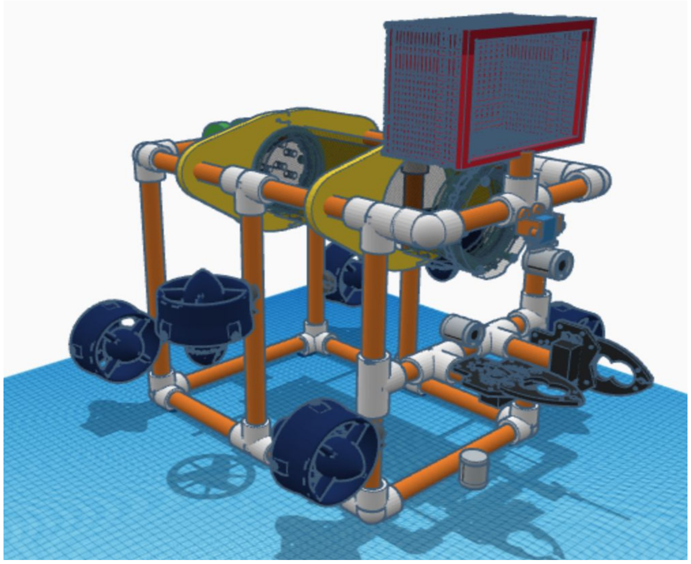
Control Subsystems	Responsibilities
Topside Control Unit	Building an easy-to-troubleshoot TCU to house above-water electronics
Watertight Enclosure	Building a custom watertight enclosure to house underwater electronics
Tether	Design a tether to minimize voltage drop & maximize ROV performance
Vertical Profiler	Design a vertical profiler that uses a buoyancy engine
Video Processing	Program and train an AI model to differentiate morts from live fish

ROV Mechanical Subsystems (previous page) & Control/Electrical Subsystems (above)
Credit: A. Selvakumar

Vehicle Structure

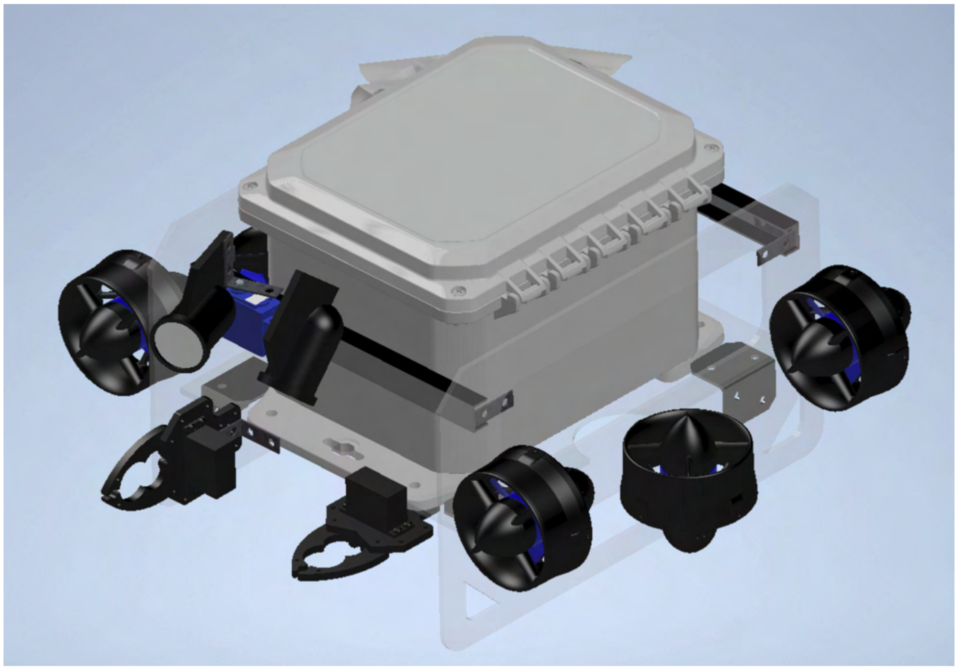
Employees referred to the competition manual to identify all stated constraints for the vehicle structure, particularly **size and weight**. Though no size restrictions are in place, the design team sought to minimize *Reverie*'s size for maneuverability purposes. The design team also noted that to achieve maximum points for weight, the ROV must weigh less than 15 kilograms in air.

Initial prototypes for *Reverie* look vastly different than its current form, highlighting **design evolution**. During preseason, team mechanical engineers considered constructing a chassis from PVC pipe. While bulky and cumbersome, the pipe chassis would be highly serviceable, making inevitable changes simple. The team made a trade-off; they decided against the idea. The increase in overall vehicular size and weight was not worth the potential modularity. In its most up-to-date form (see next page), *Reverie* measures 48 centimeters long, 40 centimeters wide, and 42 centimeters tall. It weighs 14.5 kilograms, thus earning maximum points for weight. Throughout build season, engineers made several **trade-offs to minimize total ROV cost**. By choosing a relatively inexpensive chassis material in acrylic (as opposed to carbon fiber, for instance) and designing a custom watertight enclosure instead of purchasing the mainstream commercial option (see Innovation section of Design Rationale), the company prioritized high functionality at a reduced cost.



Initial Prototype for *Reverie*
Design Credit: A. Freedman

3: DESIGN RATIONALE



***Reverie* CAD**
Design Credit: A. Freedman

Vehicle Systems

★ Propulsion Subsystem

Reverie's propulsion system consists of six Blue Robotics T200 motors oriented in a standard configuration (see diagram). The propulsion subsystem team decided on T200 motors, and subsequently *Reverie*'s motor configuration, after thorough research and development efforts.

The team toyed with the idea of building *Reverie*'s thrusters, but the technical expertise necessary and waterproofing concerns, coupled with little to no functional benefit, made this a no-go. Thus, the team evaluated two commercial options:

Motor Configuration Diagram
Design Credit: V. Jagadeesan

1. Blue Robotics T200s
2. SeaBotix BTD150s

The motors provided essentially equivalent thrust forces in a 12-volt, 25-amp system. However, the T200s were **65% less expensive**. Furthermore, the design team noted the superb waterproofing of the T200 motors. They referenced an insulation (AKA hipot) test conducted by BlueRobotics in which the thruster was submerged in water and current leakage was measured at high voltage (250V) to ensure the insulation was sufficient.

During build season, the team conducted thorough testing to optimize *Reverie*'s motor configuration. Naturally, *Reverie*'s propulsion subsystem **evolved** to meet changing prototyping and testing requirements. For details, please refer to the Prototyping and Testing section of Critical Analysis. In short, the team identified *Reverie*'s velocity as more useful for completing mission tasks in a timely fashion than an additional degree of freedom and made a calculated design **trade-off.**

3: DESIGN RATIONALE

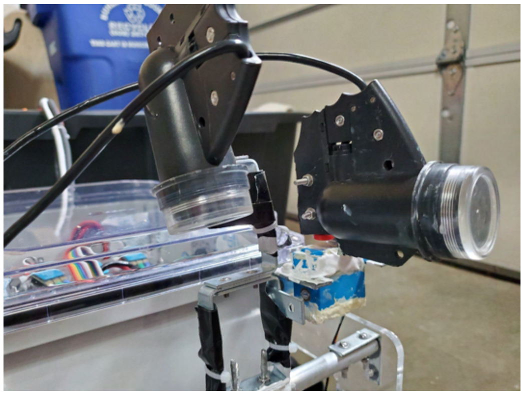
In May 2022, BlueRobotics released the T500, the latest in their line of submersible thrusters. While the team briefly considered switching *Reverie*'s T200s for T500s, they noted two concerns. First, the switch would take away from valuable time the operations team may otherwise use for product demonstration practice. Second, and perhaps more importantly, the T500s achieve maximum performance at 24 volts, achieving a 70% performance boost without any additional **power consumption**; at 12 volts, this difference is far less significant. With *Reverie*'s 12 volt, 25 amp system, no available option exists to boost thruster performance without also increasing power consumption, which would break competition rules.

★ Vision Subsystem

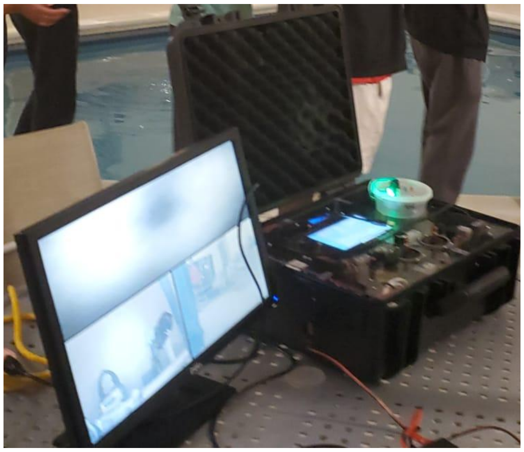
Reverie's dynamic vision subsystem features three fishing cameras. The first camera (not pictured) is mounted below the watertight enclosure and faces downward, enabling the ROV to find and map the location of the *Endurance* by flying a transect. The second camera offers the pilot a view of the ROV manipulators. The third camera makes the vision subsystem dynamic; it is mounted to a servo and operated by a knob in the topside control unit, offering a 180 degree view of Reverie's surroundings. This camera is crucial to, among other tasks, measuring fish size and farming seagrass.

This subsystem prioritizes client usability. Two camera signals are sent to an in-box monitor for easy access. All three signals are multiplexed and output as HDMI to a external display. The multiplexed signal is also output as USB using a capture card, for integration with a laptop.

All three cameras are reused and repurposed fishing cameras; they were donated to the company by a local STEM program that had excess. The company's control systems specialists disconnected the cameras from their native power supplies, removed their ballast, and cut them to size. The reused cameras still send a clear signal without interference, thus still meeting mission requirements.



Manipulator Camera and Servo-Mounted Camera
Photo Credit: A. Selvakumar



In-Box Monitor and External Display
Photo Credit: M. Pugh

★ Manipulator Subsystem

The manipulator subsystem prioritizes mission efficacy and modularity. It features two servo-powered grippers. The design team seriously considered implementing grippers powered by linear actuators, but decided against the idea. For the justification of this decision, please refer to the Engineering Design Rationale section of Design Rationale.

3: DESIGN RATIONALE

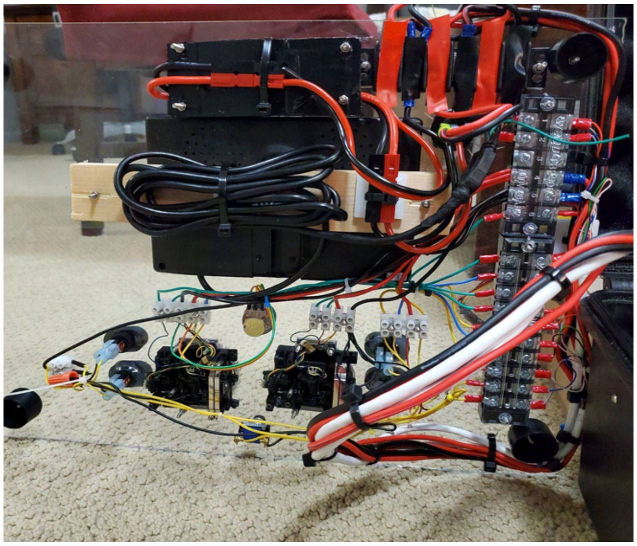
The grippers enable the pilot to replace a damaged section of power cable, replace a damaged buoyancy module, remove marine growth, and collect morts -- all missions included in the MATE Center's request for proposals.

The lateral mounting rod (see image to the right) has another pipe however, to easily attach and detach mission-specific attachments. For example, the magnetic attachment pictured helps *Reverie* pull the ferrous pins holding the ghost net suspended in the water column.

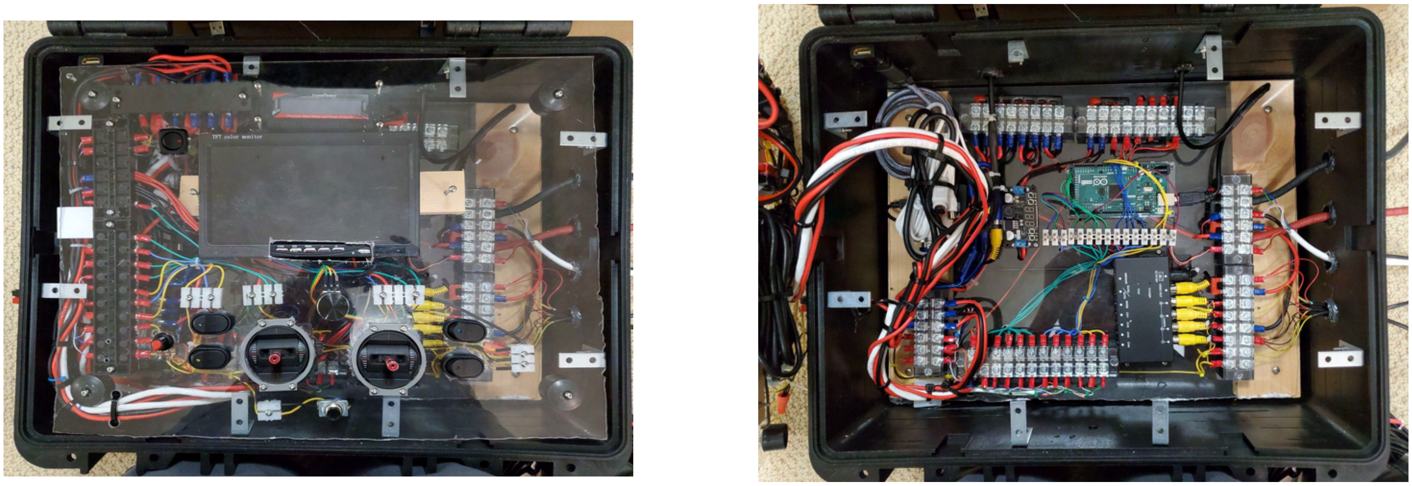
Manipulator Subsystem
Photo Credit: A. Selvakumar

Control/Electrical System

★ Topside Control Unit (TCU) Subsystem



The topside control unit is built from a repurposed Pelican case. It houses all forms of pilot input (knobs, joysticks, switches), an in-box monitor, a watt meter, Arduino microcontroller, RCA multiplexer, voltage regulators, and a video capture card. With safety in mind, the control systems team connected a 25-amp fuse in series with the power supply and routed power through a kill switch, to shut off the ROV in case of an emergency. The watt meter reads input voltage, intensity, and wattage, which can be used to determine if the battery is low and troubleshoot the system as a whole.



Topside Control Unit (TCU)
Photo(s) Credit: A. Selvakumar

3: DESIGN RATIONALE

A priority was placed on ensuring the safety of *Reverie*'s critical electrical connections; thus, personnel added strain relief in the form of rubber gaskets mounted to the side of the TCU to tug-proof the wiring.

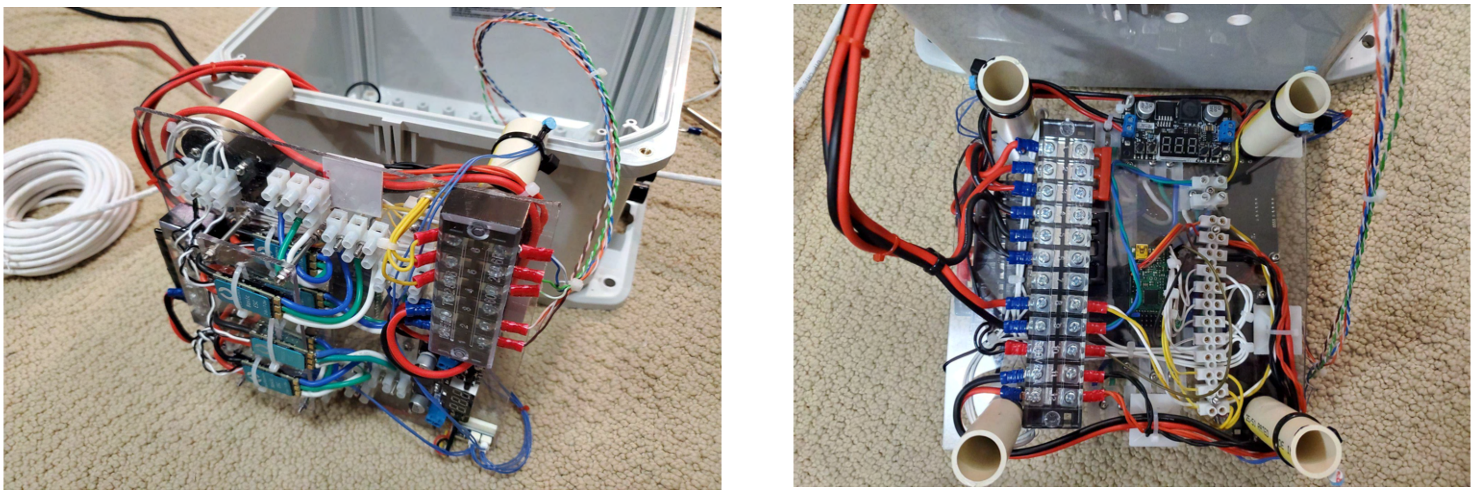
The TCU features several power distribution blocks and/or terminal strips. The setup is more aesthetically pleasing, and easier to troubleshoot, than a collection of wires and solder joints. They also minimize the number of wires required to be run down the tether; all power is routed through two 8 AWG cables, one for 12 volt power, and one for ground.

In brief, two parallel processes are happening in the TCU:

1. The Arduino microcontroller collects input from two joysticks, a potentiometer, and four push button switches. It parses this input and generates an array of nine outputs (six for T200 thrusters, two for servo-powered grippers, and one for the servo-mount camera). The nine output values are encoded and sent down a two-wire pair to a Maestro servo controller in the enclosure through serial communication, for distribution to onboard components.
2. Power is distributed to the three camera tethers; three incoming signals are sent through a terminal strip to the RCA multiplexer. Two of the incoming signals are also sent to the in-box monitor. The multiplexed signal is split; the first signal is converted to HDMI and sent to an external display, and the second is sent to a video capture card.

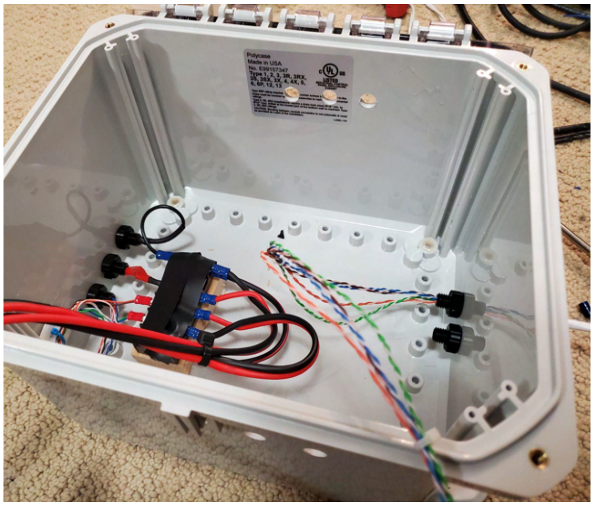
★ Watertight Enclosure (WTE) Subsystem

Reverie's custom watertight enclosure is built from a repurposed junction box. It is 400% less expensive than the commercial alternative used by nearly 80% of Ranger companies with a WTE in the 2020-21 competition season. For justification of the decision to build an enclosure from scratch, please refer to the Innovation section of Design Rationale. The WTE houses a Maestro servo controller, SOS Leak Sensor, voltage regulator, and electronic speed controllers (ESCs).



WTE Electronics Tray
Photo(s) Credit: A. Selvakumar

3: DESIGN RATIONALE

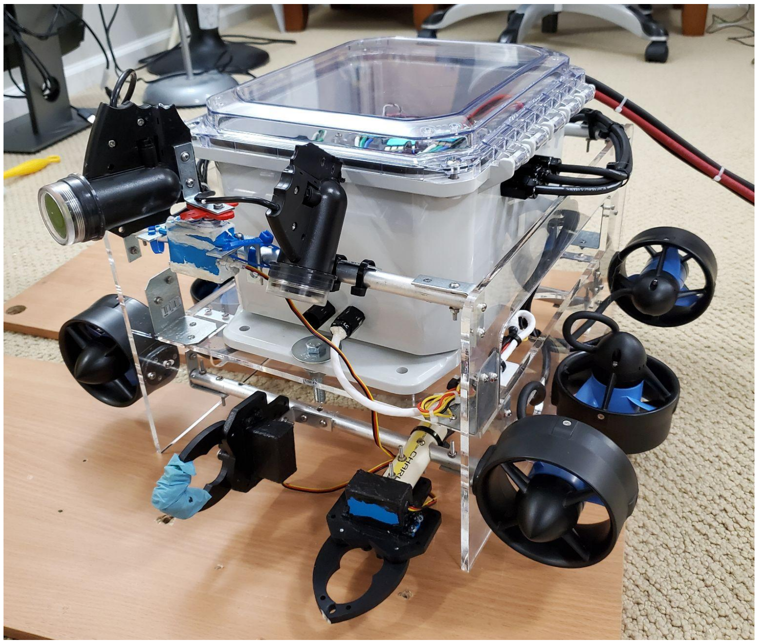


Wires entering the WTE
Photo Credit: A. Selvakumar

All electronics housed in the WTE are mounted to an acrylic **electronics tray**. The tray is elevated to protect the control system's integrity in case of a leak. It is also removable for easy access & troubleshooting.

Wires enter the WTE through cable penetrators and are immediately sent through terminal strips; this makes quick fixes (replacing a cable, checking conductivity, etc) simple. A set of cables connects the terminal strips to the enclosure tray.

The WTE houses the aforementioned **Maestro servo controller** (MSC). The MSC decodes the serial values sent from the topside Arduino microcontroller and outputs nine PWM signals to six thrusters, two servo-operated grippers, and a servo-mount camera. The enclosure houses an **SOS Leak Sensor**, a crucial safety feature that alerts the team if water penetrates the enclosure's seal. The sensor uses four re-usable sponge tipped probes with an adhesive backing; if water meets a sponge, it will swell and connect two wires, completing a circuit. The sensor then sends a positive output to the TCU, which notifies the pilot.



Reverie **ROV**
Photo Credit: A. Selvakumar

The WTE also houses six **ESCs**. These are necessary to run the brushless T200 thrusters, which operate on three-phase power. Each ESC connects to a single motor using three wires, is powered using two wires, and requires only one wire for data transmission. While transmission would typically require an additional cable (namely a ground wire), the controls team discovered an internal ground was in use, i.e. the data ground and power source ground were already conductive.

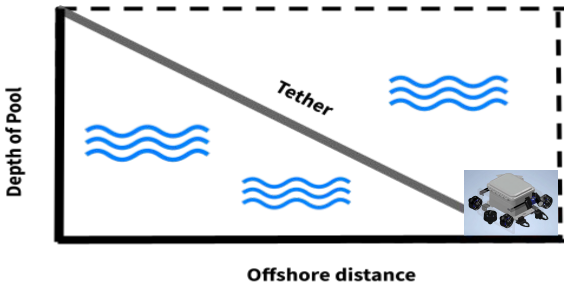
To reinforce the **waterproofing** of the junction box and cable penetrators, company employees added marine epoxy to the exterior of the WTE. They also added a 1.5 centimeter thick layer of resin to the base of the junction box.

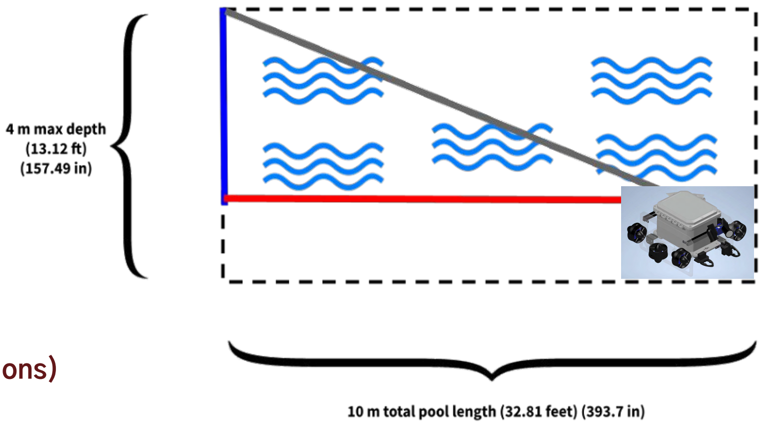
3: DESIGN RATIONALE

★ Tether Subsystem

Requirements – As per mission requirements, *Reverie* must be capable of operating a maximum depth of 4 meters (13 feet) and a maximum offshore distance of 10 meters (32 feet). Upon the RFP's release, the team used basic geometry to calculate a minimum tether length. Using the Pythagorean theorem, *Reverie* needs 10.36 meters (approximately 34 feet) of tether from the poolside. After accounting for the distance from the pilot's seat to poolside and additional slack, company employees concluded the tether length would be 13 meters (43 feet).

Design – The ROV tether consists of six cables: one 8 AWG conductor for 12-volt power, one 8 AWG conductor for ground, an eight-conductor 24 AWG Ethernet cable for signals routed through the WTE (serial communication to the Maestro, input from the SOS Leak Sensor), and three three-conductor, 30 AWG cables that carry power, ground, and signal to each camera.





Tether Length Diagrams (Reference & Calculations)
Design Credit: V. Jagadeesan

Tether Management Protocol – Additionally, tether management is crucial to keep the ROV in perfect working condition. The company's JSOs created a tether management checklist:

01 **During Deployment**	❏ Tether must be properly managed so it does not pose as a tripping hazard for poolside employees. ❏ Tether manager must be sure to properly control the tether while the pilot is maneuvering *Reverie* in the water. ❏ Strain reliefs are properly attached to keep the tether secure to the frame.
02 **Workplace Management**	❏ Tether must be kept away from sharp tools and objects to prevent nicks or cuts that may cause damage. ❏ Keep tether neatly coiled so it doesn't get tangled, twisted or knotted

Tether Management Checklist
Design Credit: A. Amarnath & V. Jagadeesan

3: DESIGN RATIONALE

Buoyancy and Ballast

ρ - density of fluid (g/cm^3)
V - volume of fluid (cm^3)
g - acceleration due to gravity (m/s^2)
m - mass of object (g)

$$\rho V g = mg$$
$$(1)(14{,}500)(9.81) = m(9.81)$$
$$m = 14{,}500 \text{ grams} = 14.50 \text{ kilograms}$$

Buoyancy Calculations
Credit: A. Selvakumar & A. Freedman

Reverie is neutrally buoyant, this means its average density is equal to the density of the fluid in which it is immersed; this makes it resistant to hydrostatic pressure and able to explore deeper depths for extended period of time. Perhaps more importantly, it ensures the pilot need not correct for a tendency to ascend or descend.

Company employees used **Archimedes' Principle** and basic arithmetic to make *Reverie* neutrally buoyant. While the chassis and payload are naturally negatively buoyant, the air spaces within the WTE lower its density, and make it extremely positively buoyant. Before any modifications, the ROV displaced approximately 14,500 cm^3 and weighed 11.34 kilograms; despite the significant weight, the robot was positively buoyant overall. Volume was determined using the water displacement method; the ROV was submerged in a bucket full of water and the volume of the spillage was calculated later. The operations team made the calculations to the right to determine how much the ROV should weigh to become neutrally buoyant.

After the team **added 3.16 kilograms of ballast** to *Reverie*, it achieved neutral buoyancy, verifying the calculations experimentally. In practice, the team has not found a need for a variable ballast system. *Reverie*'s propulsion subsystem is capable of providing enough vertical thrust to lift every item outlined in the mission specifications.

Payload and Tools

★ Sensor Design Rationale

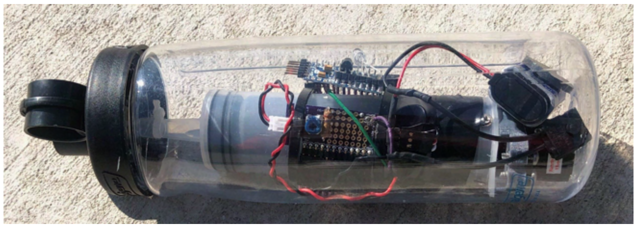
The company outlined the system's basic functional requirements from the mission specifications (see Systems Approach section of Design Rationale). The design team noted sensors were not strictly necessary for any specific mission tasks. That being said, given the implementation of the watertight enclosure, company JSOs pushed for the implementation of an SOS Leak Sensor (see WTE Subsystem section of Vehicle Systems in Design Rationale).

★ Cameras

Reverie's dynamic vision subsystem features **three Aqua-Vu fishing cameras**. The cameras are integral for all subsea tasks; they offer the pilot a thorough view of *Reverie*'s surroundings for general navigation. The best part about the fishing cameras is they come pre-waterproofed; the team's control systems specialists have attempted several methods of waterproofing less expensive car backup cameras to limited success. While more expensive in the short run, implementing the fishing cameras likely saved the company money; the cost of several replacement car backup cameras, and the time lost to repair efforts, would surely have added up over time. The fishing cameras have RCA output, the same as the camera multiplexer, ensuring easy compatibility with the existing system For a justification for the **number and placement** of cameras, please refer to the Vision Subsystem section of Vehicle Systems in Design Rationale.

3: DESIGN RATIONALE

★ Vertical Profiling Float

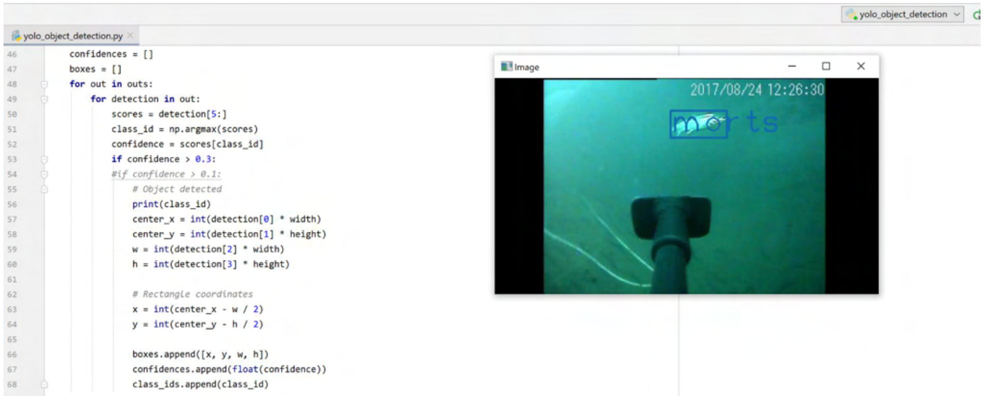


Vertical Profiling Float
Photo Credit: A. Amarnath

In **Task 3.1** ***MATE Floats!***, the company was asked to design and construct an operational vertical profiling float. This underwater float is a non-tethered, autonomous robot that has no propeller and uses little energy. A 9-volt lithium rechargeable battery is used to power this system. The syringe is controlled via stepper motor, which is controlled by an Arduino Pro Mini. When signalled (by an IR remote), the Arduino spins the motor and a threaded rod, expanding the syringe, which lets water in. The stepper motor spins in reverse to close the syringe. The vertical profiling float moves by changing its buoyancy by taking in or expelling water. This change in buoyancy causes the float to rise and sink in the water. In terms of safety requirements, the vertical profiling float strictly follows the safety requirements created by the JSO; these ensure that electrical components are insulated from water.

★ AI Model

The team has developed an AI model capable of **differentiating live fish from "morts"** in task 2. The model implements the OpenCV and numpy libraries and the YOLOv3 training algorithm.



```
confidences = []
boxes = []
for out in outs:
    for detection in out:
        scores = detection[5:]
        class_id = np.argmax(scores)
        confidence = scores[class_id]
        if confidence > 0.3:
        #if confidence > 0.1:
            # Object detected
            print(class_id)
            center_x = int(detection[0] * width)
            center_y = int(detection[1] * height)
            w = int(detection[2] * width)
            h = int(detection[3] * height)

            # Rectangle coordinates
            x = int(center_x - w / 2)
            y = int(center_y - h / 2)

            boxes.append([x, y, w, h])
            confidences.append(float(confidence))
            class_ids.append(class_id)
```

AI Model in Action
Photo Credit: A. Selvakumar

Build vs. Buy, New vs. Used

Considering LHS Horizon is in its first year of operation, most resources had to be purchased commercially, though the CFO sought to repurpose and reuse as much as possible. That being said, despite implementing commercial components, every vehicle subsystem is original in design and unique in nature. The company CFO and CEO have outlined the system components that are built vs bought.

Build (in-house) – custom, laser-cut, acrylic ROV chassis; topside control unit (Pelican case repurposed, electrical components purchased); custom WTE (all components purchased); ROV manipulators (gripper kits reused, servo motors purchased); vertical profiling float (electrical components purchased); tether (Ethernet cable repurposed, all other cables purchased); AI model

Buy (outsource) – six T200 thrusters, three servo motors, junction box (for use in WTE subsystem), acrylic sheets (for use in chassis subsystem)

The team reused the following items; all items were obtained as donations by sponsors.

Reused – gripper kits, Pelican case, three Aqua-Vu fishing cameras

4: SAFETY

Safety Rationale

Safety is something we truly value here at LHS Horizon. **Our first priority is the safety of our employees, clients, and *Reverie*.** Our JSOs realize this vision by outlining and enforcing safety protocols and procedures (see next section below). The JSOs made sure to implement several safety features into *Reverie*'s various subsystems. Given these procedures and features, we are able to preserve the safety of our personnel and equipment and by so doing, guarantee *Reverie* is highly functional and efficient.

Safety Procedure Checklists

Construction Safety Procedures Checklist:

- ☐ Environment must be organized before operating or working in the workplace.
- ☐ Tools must be handled with proper care for prolonged functionality and employee protection.
- ☐ *Use the right tools for the right purposes.*
- ☐ PPE equipment, including goggles, gloves and head covers MUST be worn when using more hazardous equipment, including power tools (drills, saws, heat gun), soldering iron, or chemicals.
- ☐ Power tools must be unplugged when not in use.
- ☐ Workplace must be cleaned and tools must be stored back into its respective places when done utilizing.

Operation Safety Procedures Checklist:

Before deploying *Reverie:*

- ☐ Make sure that the ROV, its systems and components are all turned on, functioning, and/or attached in a secure manner.
- ☐ The tether should be organized and coiled neatly.

During deployment:

- ☐ Gently place the ROV into the water
- ☐ It should not spin, as that would entangle the tether under the water and prevents mobility.
- ☐ Observe for malfunctions (e.g. motor failure) and should regularly check the SOS leak sensor LED (will discuss below). This is so the robot can immediately resurfaced and be inspected to quickly fix & redeploy it.

Afterwards:

- ☐ Bring the ROV up to the surface; power off and dry it (open the enclosure lid so the condensation that might have accumulated inside can be let out).
- ☐ Make any repairs as necessary before properly storing away the ROV, tether, and control box for later use.

4: SAFETY

Safety Features

Below are some of the safety features the company's JSOs chose to highlight. Certain safety precautions related specifically to the tasks outlined in the MATE Center's request for proposals; these are bolded.

	Safety Features
Fuses	Fuses are crucial precautions that ensure electrical malfunctions do not lead to permanent damage. The system contains a 25-amp inline fuse.
Strain Relief	Strain reliefs prevent our cables and connections from experiencing stress. They also hold the tether in place, straight out the back of the ROV. This **enables *Reverie* to smoothly and accurately fly a straight transect over the wreck of the *Endurance*.**
Kill Switch	In the event of an emergency, clients operating the control system can manually shut down off power. This could prove useful in the event of a short-circuit or electrical accident.
Watt Meter	The watt meter is used to monitor the voltage and amperage of our control system. The operations team can use the meter to identify abnormal readings and stave off large-scale system issues before they arise.
Motor Shrouds	Motor shrouds prevent foreign substances from interfering with motor function and protect our employees from propeller cuts. The shrouds are wrapped with black and yellow caution tape that warns employees of a physical hazard.
Thruster Guards	The 3D-printed casings protect employees from the ROV thrusters and block potential debris from interfering with thruster movement. They are rated IP20 meaning that no object larger than 12.5mm will able to penetrate them. This **prevents damage to marine life (namely, the seagrass) and stops items such as the ghost net from interfering with thruster performance.**
Water-proofing	Waterproofing **prevents current leakage that could harm the marine biome, particularly fish stock.** The cameras come pre-waterproofed, as do the thrusters and servo motors. The watertight enclosure that houses underwater components is further reinforced with resin and marine epoxy to prevent water entering alongside tether wires
SOS Leak Sensor	A Blue Robotics SOS Leak Sensor was implemented inside the enclosure to warn the operations team if there has been any leakage. Our engineers have programmed the sensor so when water has leaked into the provided probes, an LED on the topside will light up.

***Reverie*'s Safety Features**
Credit: A. Selvakumar, A. Tornese, & V. Jagadeesan

5: CRITICAL ANALYSIS

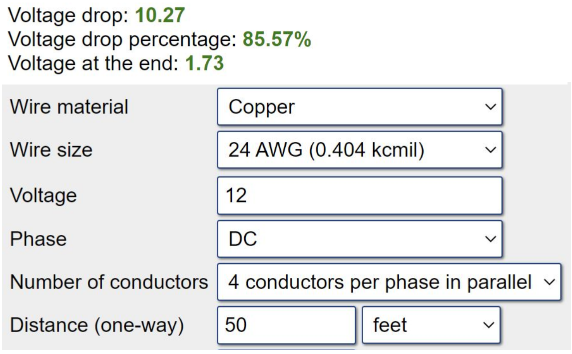
Prototyping and Testing

During preseason and the early stages of build season, the company's leaders allocated personnel to research and development (R&D) efforts, namely prototyping and testing. Prototyping is a crucial process by which design teams ideate, experiment with, and bring concepts to life. The company's CEO has worked with design leads to outline the R&D initiatives with the greatest tangible impact on *Reverie*, the end product.

Voltage Drop Optimization & the Tether Subsystem:

- The initial control system overview used four 24 AWG conductors wired in parallel to carry twelve volts from the topside control unit to components underwater. End-to-end system testing later demonstrated the cables could not reliably sustain a twenty-five amp current. Voltage drop calculations later verified this observation (see data to the right).
- The company's control system specialists conducted a series of voltage drop calculations to determine the optimum power cabling. Calculations indicated an 8 AWG red-black wire pair could sustain the requisite current. In further testing, personnel measured the maximum amperage capacity, and corresponding net horizontal thrust of both system prototypes.
- Testing data indicates the latter system is far more efficient. Thus, *Reverie*'s most up-to-date control system features an 8 AWG wire pair as power cabling.

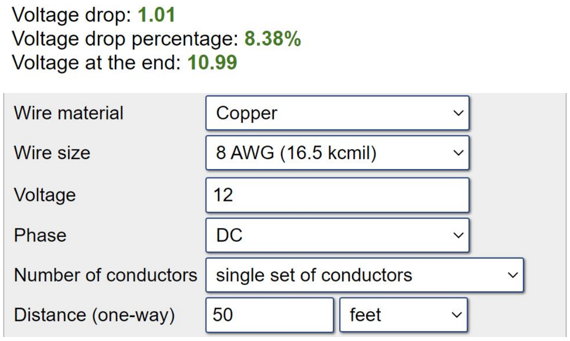
Voltage Drop (Initial Control System):



Voltage drop: **10.27**
Voltage drop percentage: **85.57%**
Voltage at the end: **1.73**

Wire material	Copper
Wire size	24 AWG (0.404 kcmil)
Voltage	12
Phase	DC
Number of conductors	4 conductors per phase in parallel
Distance (one-way)	50 feet

Voltage Drop (Updated Control System):



Voltage drop: **1.01**
Voltage drop percentage: **8.38%**
Voltage at the end: **10.99**

Wire material	Copper
Wire size	8 AWG (16.5 kcmil)
Voltage	12
Phase	DC
Number of conductors	single set of conductors
Distance (one-way)	50 feet

Voltage Drop Calculations
Photo(s) Credit: A. Selvakumar

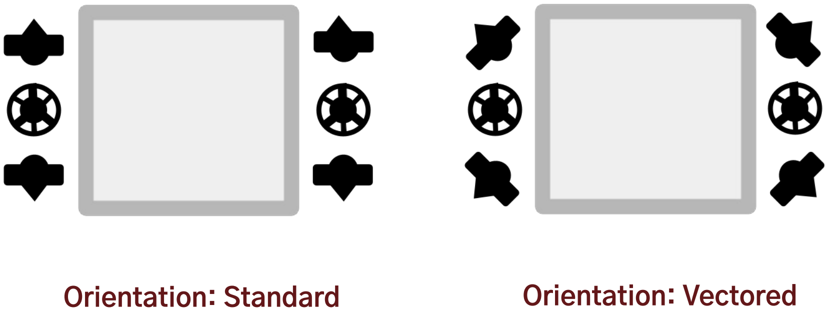
	Initial Control System	Updated Control System
Voltage Drop (V)	10.27	1.01
Amperage Capacity (A)	7.56	24.08
Net Horizontal Thrust (kgf)	3.56	7.64

Tether Subsystem Optimization Testing Data Table
Credit: A. Selvakumar & V. Jagadeesan

5: CRITICAL ANALYSIS

Thruster Orientation & the Propulsion Subsystem:

- ★ During the early stages of propulsion subsystem development, the mechanical team considered testing different thruster system orientations.
- ★ The vectored orientation places each horizontal motor at 45 degrees relative to the chassis' longitudinal axis; the standard orientation places each horizontal motor parallel to the chassis' longitudinal axis (see diagram to the right).
- ★ Through trigonometry, the mechanical team determined that the vectored configuration, while offering an additional degree of freedom, would lower forward & reverse thrust by nearly 30%.
- ★ The trial data to the right indicates the theoretical calculations apply in practice.
- ★ *Reverie*'s pilot and the company CEO decided this drawback of the vectored configuration outweighed any potential benefits.



Thruster Orientations
Credit: V. Jagadeesan

	Time taken to travel 25 meters (seconds)
Vectored Orientation	30.6
Standard Orientation	20.8

Thruster Configuration Testing
Credit: A. Selvakumar & V. Jagadeesan

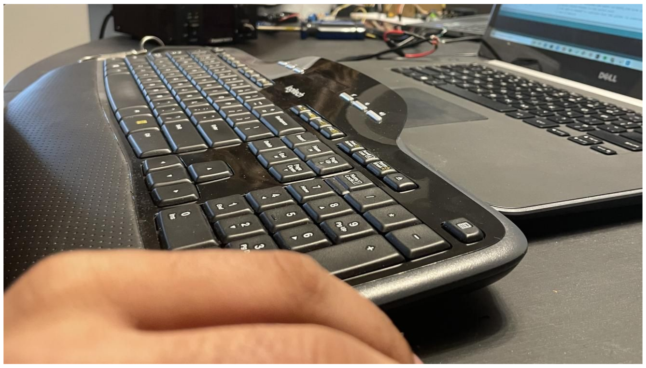
Vehicle Testing Methodology

As competition season approached, the team conducted multiple aquatic trials at local pools to test *Reverie* and its operations team. During trial runs, *Reverie*'s pilot provides feedback on the performance of each individual subsystem; he indicates any tuning he would like to be done to the vehicle's buoyancy, propulsion, or manipulators. Through repeated testing and manipulation, the operations team could optimize each vehicle subsystem.

Preparation for the product demonstration occurred in three stages. The first stage involved *Reverie*'s pilot and the operations team becoming familiar with the system, its controls, and poolside operational and safety procedures. The second stage involved targeted skills practice. The pilot outlined a list of specific skills necessary for the demonstration and evaluated how adept he was at each. He spent a few trials targeting his weaknesses through repeated practice. The last stage involved full 15-minute demonstration runs. The focus of such practice was for the operations team to establish communication protocols. The team credits the aforementioned three-stage testing methodology to the company's above-average performance at the 2022 Mid-Atlantic Pennsylvania Regional, despite having less practice time than anticipated.

5: CRITICAL ANALYSIS

Troubleshooting Methodology



Employees troubleshooting the Arduino control algorithm
Photo Credit: M. Pugh

Troubleshooting is a critical component of ensuring *Reverie* always operates at peak performance. During the company's first year of operations, personnel have learned to troubleshoot effectively; employees have a feel for when to revisit basic techniques or experiment with new methods. Put quite simply, troubleshooting is dependent on an overall understanding of the vehicle system and its components. Sometimes, issues are simple and easily remedied (such as unplugged wires or missing grounds), but oftentimes they are not as tangible; examples include wire interference and poor electrical connections (AKA cold joints). On the next page, the control systems team indicates the series of quick checks they perform in the event of a vehicular malfunction.

Troubleshooting Strategies and Techniques

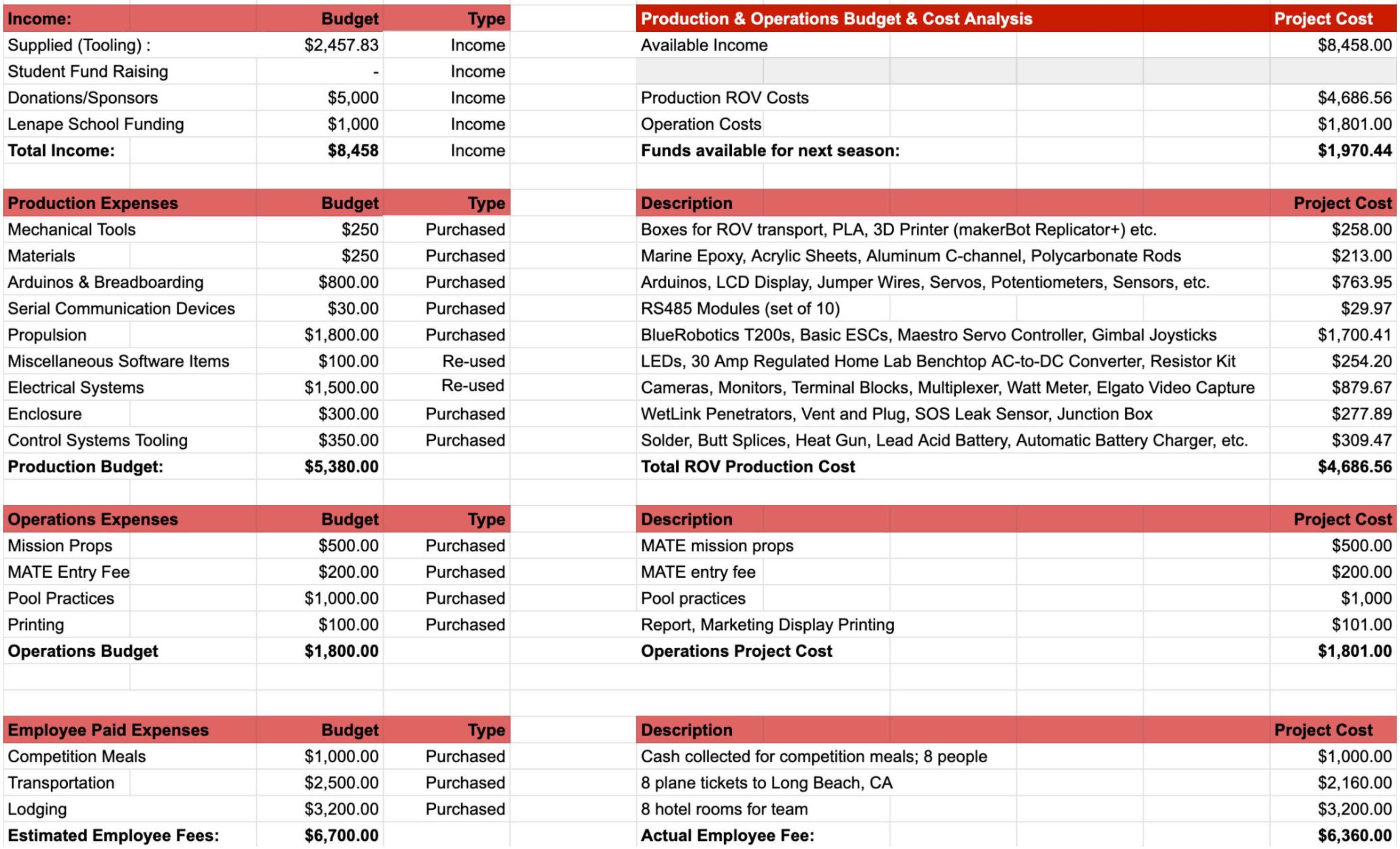
- ★ Control Box
    - ○ Ensure the fuse is intact.
    - ○ Check conductivity between system power and ground.
    - ○ Check that wires are not loose or broken.
        - ■ Check the microcontrollers' I/O pins.
        - ■ Check whether any forked terminals are unfastened/whether any screws in the terminal blocks are loose.
        - ■ Check that all voltage regulators are delivering the correct voltage.
- ★ Electronics Enclosure
    - ○ Check the LED indicator on the SOS Leak Sensor
    - ○ Remove the ROV from the water, open the watertight container, let any water evaporate, then check the integrity of each component and reseal.
- ★ Hardware Components (incl. HS-646WP Servo and Fishing Cameras)
    - ○ Switch component out with a replacement known to work.
    - ○ Connect to the component directly (i.e. not through the tether).
    - ○ Ensure common ground connection.
    - ○ Check for overheating.
- ★ Uploading Complications
    - ○ Verify the program for errors; check the board and port are correct.
    - ○ Switch the microcontroller out with a replacement known to work.
    - ○ Restart the computer.

6: ACCOUNTING

Budget and Project Costing

During preseason, the company's CFO prepared a budget with estimated expenses based on actual project costing from prior hobbyist work. Because *Reverie*'s control system takes inspiration from previous projects, the company's project budget was easier to forecast; it allowed the CFO to focus on cost estimates for ROV enhancements (including the custom-cut acrylic chassis, custom watertight enclosure, and aluminum tubing) and new tools. Furthermore, employee transportation and meal expenses, while noted, are listed separately; company employees are responsible for these costs.

Net project income was estimated based on early negotiations with sponsors and company partners. The projected budget was shared with school & district administrators to ensure adherence on the company's part. All receipts for purchases were kept in a project costing folder that the CEO reviewed monthly. The 2021-22 season Budget and Project Costing report is shown below.



Income:	**Budget**	**Type**
Supplied (Tooling) :	$2,457.83	Income
Student Fund Raising	-	Income
Donations/Sponsors	$5,000	Income
Lenape School Funding	$1,000	Income
Total Income:	**$8,458**	Income
Production Expenses	**Budget**	**Type**
Mechanical Tools	$250	Purchased
Materials	$250	Purchased
Arduinos & Breadboarding	$800.00	Purchased
Serial Communication Devices	$30.00	Purchased
Propulsion	$1,800.00	Purchased
Miscellaneous Software Items	$100.00	Re-used
Electrical Systems	$1,500.00	Re-used
Enclosure	$300.00	Purchased
Control Systems Tooling	$350.00	Purchased
Production Budget:	**$5,380.00**	
Operations Expenses	**Budget**	**Type**
Mission Props	$500.00	Purchased
MATE Entry Fee	$200.00	Purchased
Pool Practices	$1,000.00	Purchased
Printing	$100.00	Purchased
Operations Budget	**$1,800.00**	
Employee Paid Expenses	**Budget**	**Type**
Competition Meals	$1,000.00	Purchased
Transportation	$2,500.00	Purchased
Lodging	$3,200.00	Purchased
Estimated Employee Fees:	**$6,700.00**	

Production & Operations Budget & Cost Analysis	**Project Cost**
Available Income	$8,458.00
Production ROV Costs	$4,686.56
Operation Costs	$1,801.00
Funds available for next season:	**$1,970.44**
Description	**Project Cost**
Boxes for ROV transport, PLA, 3D Printer (makerBot Replicator+) etc.	$258.00
Marine Epoxy, Acrylic Sheets, Aluminum C-channel, Polycarbonate Rods	$213.00
Arduinos, LCD Display, Jumper Wires, Servos, Potentiometers, Sensors, etc.	$763.95
RS485 Modules (set of 10)	$29.97
BlueRobotics T200s, Basic ESCs, Maestro Servo Controller, Gimbal Joysticks	$1,700.41
LEDs, 30 Amp Regulated Home Lab Benchtop AC-to-DC Converter, Resistor Kit	$254.20
Cameras, Monitors, Terminal Blocks, Multiplexer, Watt Meter, Elgato Video Capture	$879.67
WetLink Penetrators, Vent and Plug, SOS Leak Sensor, Junction Box	$277.89
Solder, Butt Splices, Heat Gun, Lead Acid Battery, Automatic Battery Charger, etc.	$309.47
Total ROV Production Cost	**$4,686.56**
Description	**Project Cost**
MATE mission props	$500.00
MATE entry fee	$200.00
Pool practices	$1,000
Report, Marketing Display Printing	$101.00
Operations Project Cost	**$1,801.00**
Description	**Project Cost**
Cash collected for competition meals; 8 people	$1,000.00
8 plane tickets to Long Beach, CA	$2,160.00
8 hotel rooms for team	$3,200.00
Actual Employee Fee:	**$6,360.00**

Budget and Project Costing Calculation Report
Credit: V. Jagadeesan, A. Selvakumar, S. Soma

7: ACKNOWLEDGEMENTS & REFERENCES

Acknowledgements

MATE Center and Marine Technology Society – sponsoring this year's competition
MATE Inspiration and Innovation (MATE II) – managing the MATE competition
National Science Foundation – funding the MATE program
Long Beach City College – hosting the 2022 MATE World Championship
Oceaneering International – their support of the MATE competition
Lenape High School & the Lenape Regional High School District (special shoutouts to Mr. Laddey, Ms. Krevetski, and Mr. Scott!) – financial and administrative support, mentoring
Mount Laurel Library – providing a venue for preseason meetings
Jersey Wahoos Swim Club and Charleston Swim Club – offering their pools to our company at a discounted rate
Tornese family – providing a venue for build season meetings and small pool for ROV trials
Selvakumar family – providing a venue for build season meetings and significant financial support
Mr. Matt Gardner and the 2022 MATE ROV Mid-Atlantic Regional team – organizing the regional through which the company qualified for the World Championship
Ms. Maureen Barrett – donated materials
Aayush Talreja – assistance with the early stages of company branding
Our families – their continued support and encouragement

Sponsor Logos
Credit: V. Jagadeesan & A. Selvakumar

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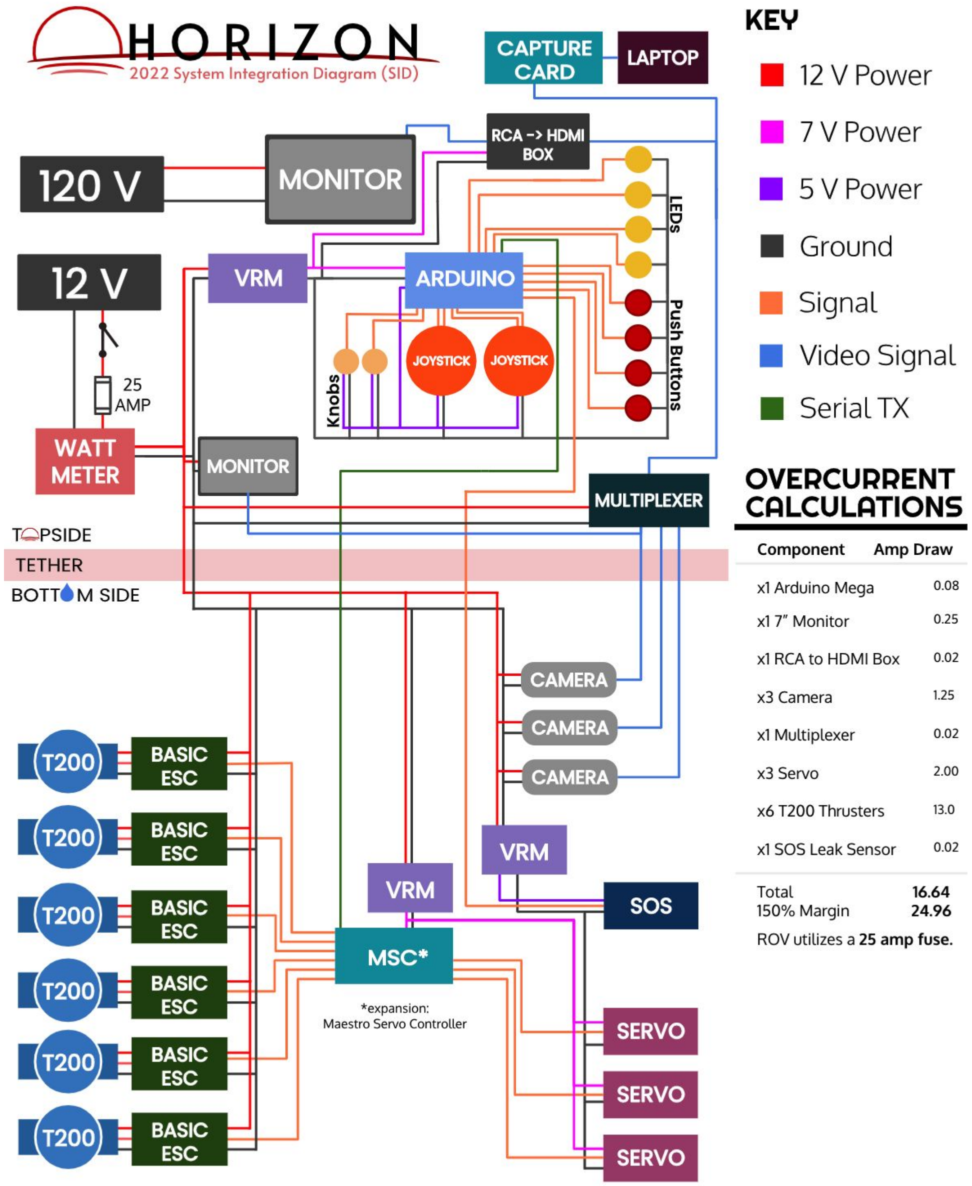
8: APPENDIX

A. Main System Integration Diagram (SID)



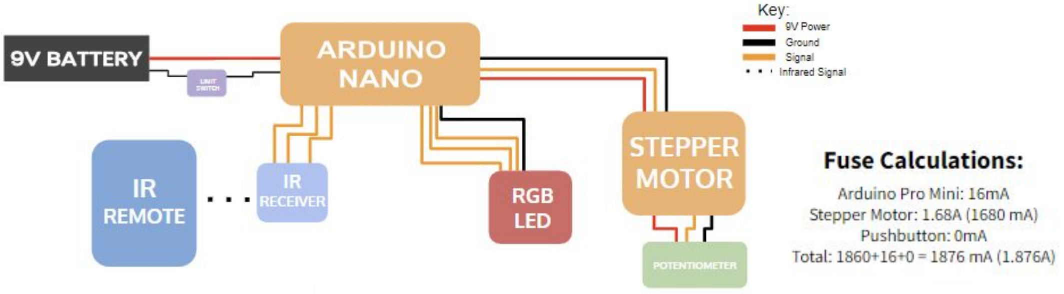
OVERCURRENT CALCULATIONS

Component	Amp Draw
x1 Arduino Mega	0.08
x1 7″ Monitor	0.25
x1 RCA to HDMI Box	0.02
x3 Camera	1.25
x1 Multiplexer	0.02
x3 Servo	2.00
x6 T200 Thrusters	13.0
x1 SOS Leak Sensor	0.02
Total	**16.64**
150% Margin	**24.96**

ROV utilizes a **25 amp fuse.**

A full diagram of *Reverie*'s end-to-end control system
Design credit: A. Selvakumar & A. Amarnath

B. Non-ROV Device System Integration Diagram (SID)



Fuse Calculations:

Arduino Pro Mini: 16mA
Stepper Motor: 1.68A (1680 mA)
Pushbutton: 0mA
Total: 1860+16+0 = 1876 mA (1.876A)

A diagram of the vertical profiler's control system
Design credit: A. Amarnath & A. Selvakumar